

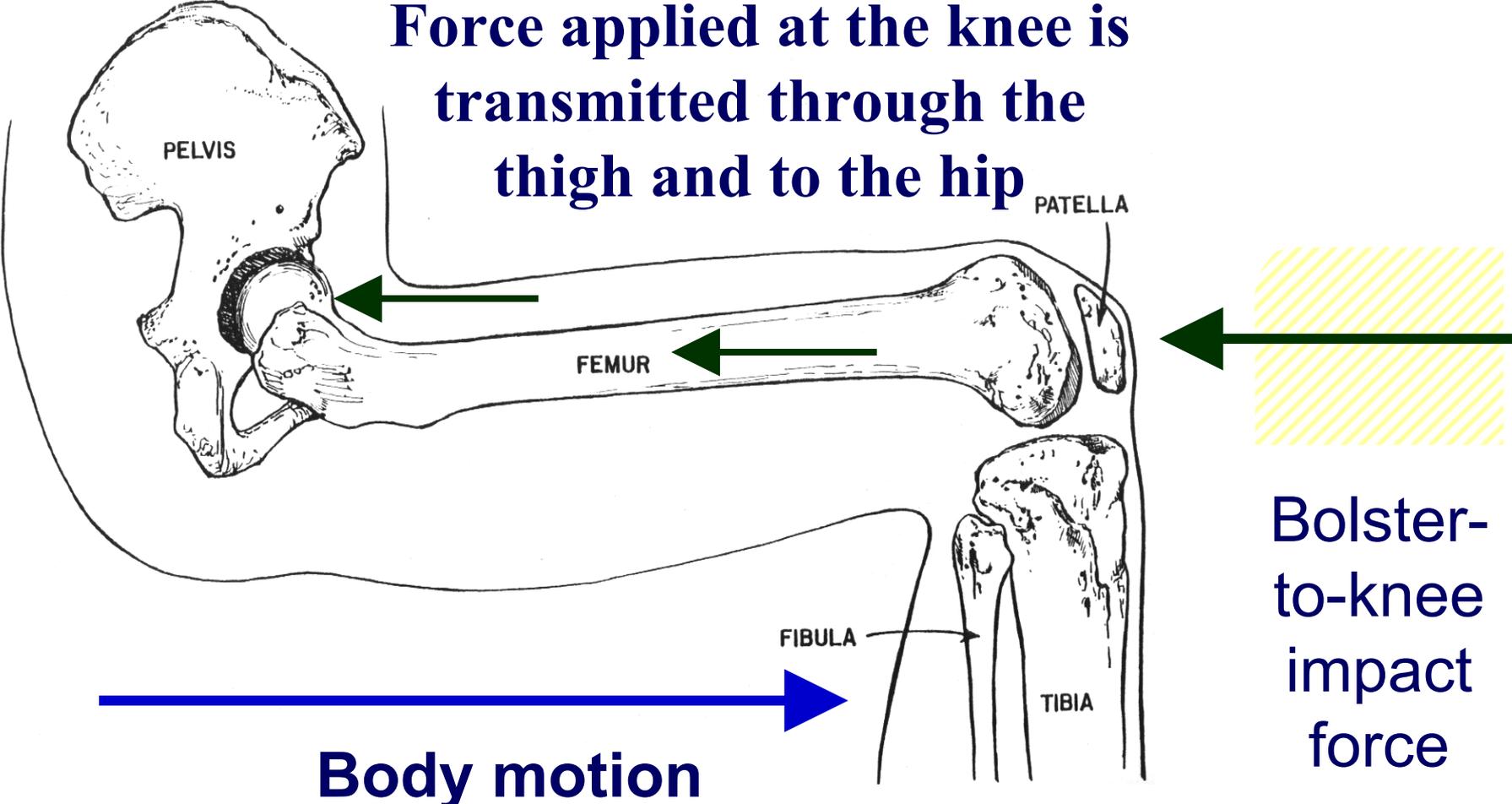
Knee-Thigh-Hip Injuries and Knee/Femur Compliance of the Hybrid III, Thor-Lx, and Human Cadavers

Shashi Kuppa, NHTSA

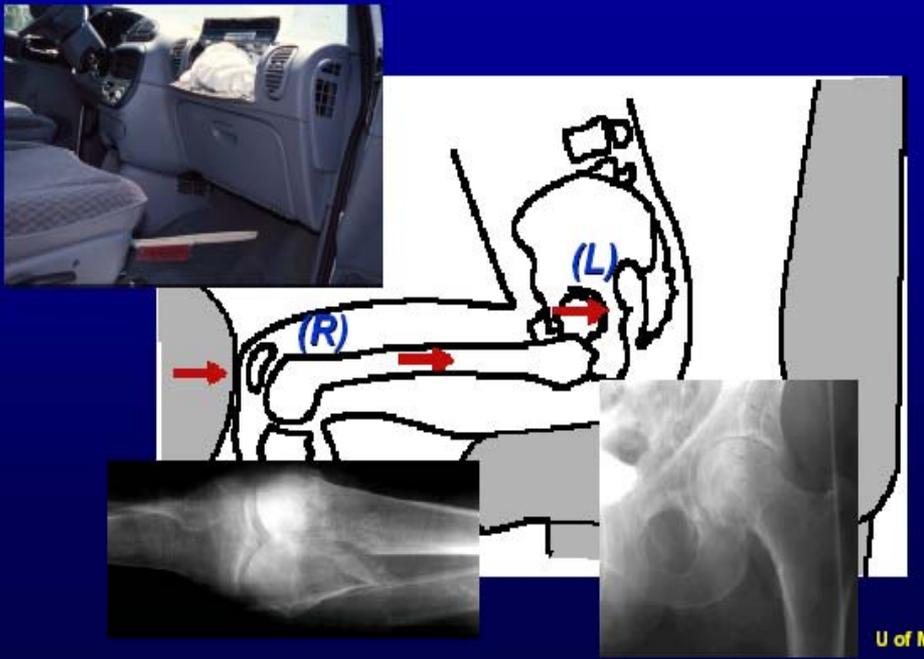
Jonathan Rupp, UMTRI

Larry Schneider, UMTRI

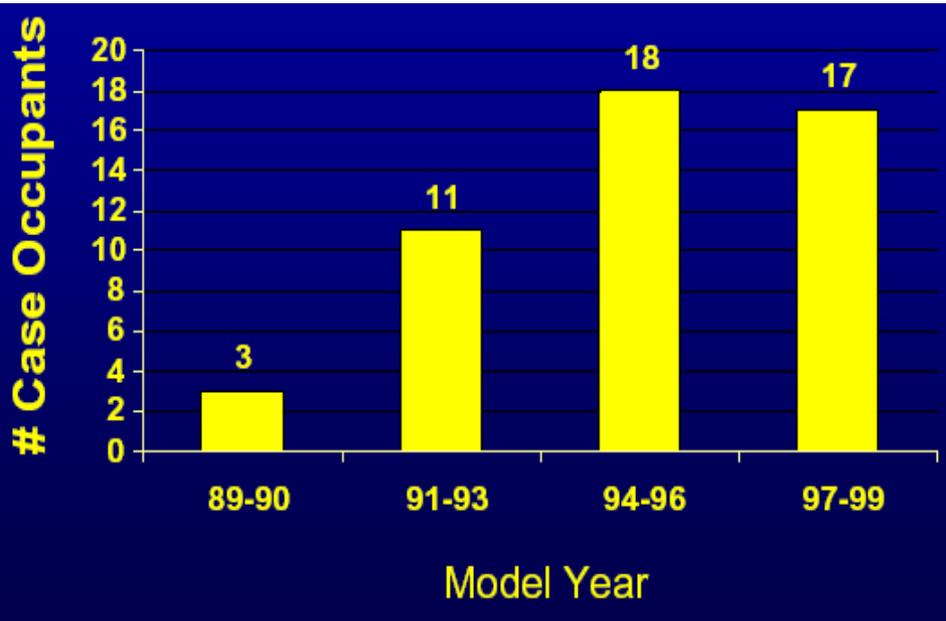
KTH Injury Scenario in Frontal Crashes



Michigan CIREN Center

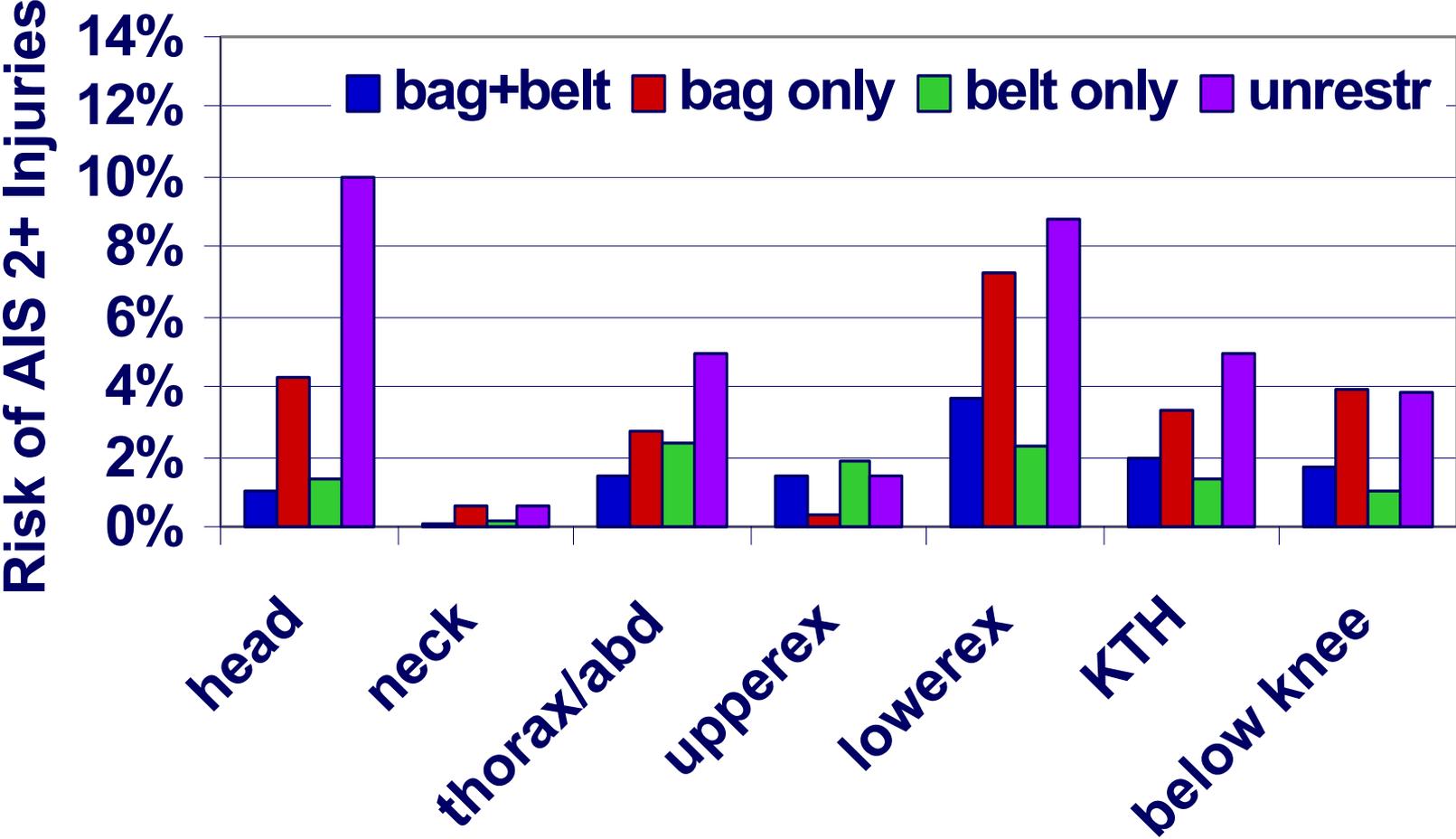


Mechanisms of injury

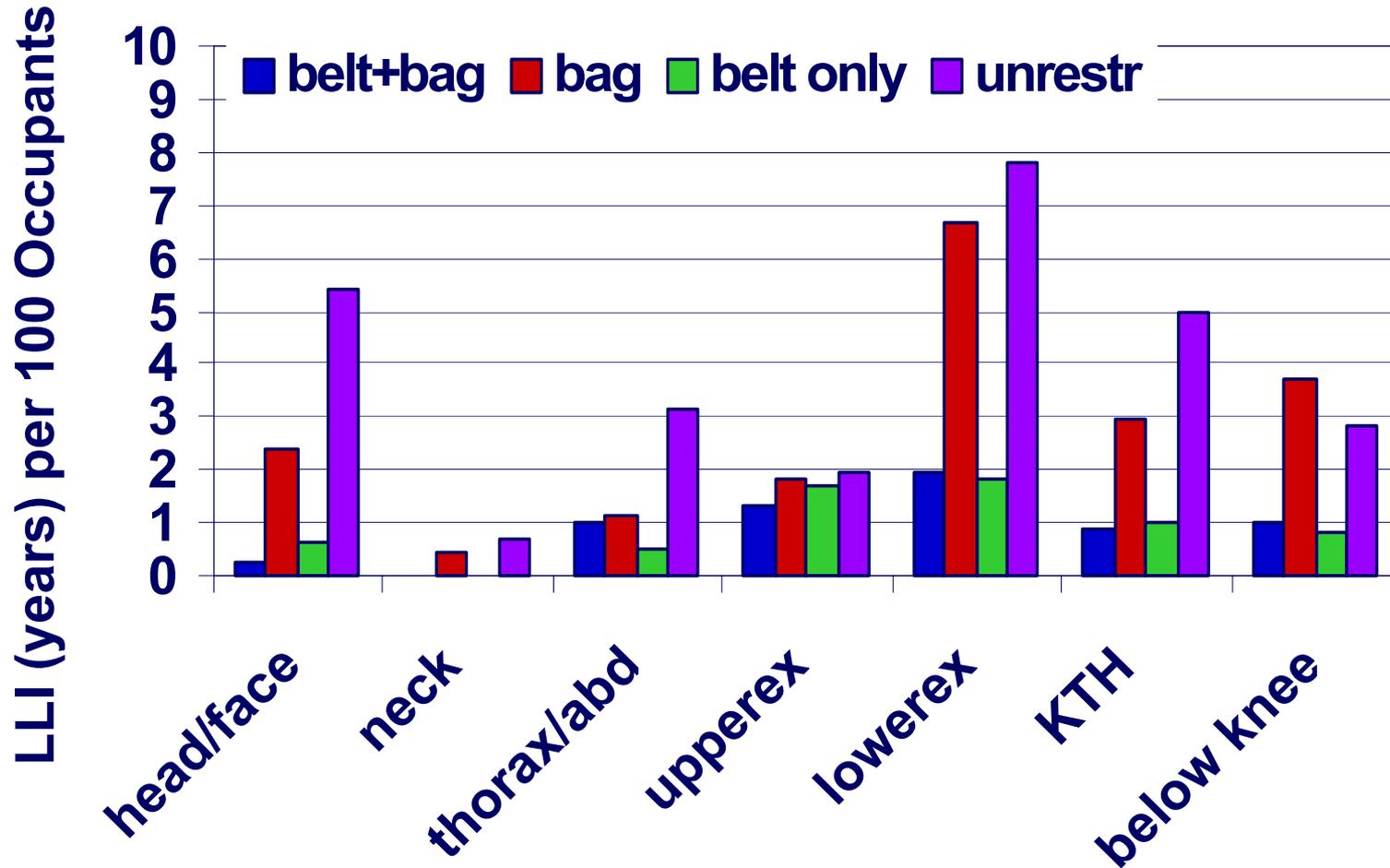


Hip injuries in Frontal Crashes

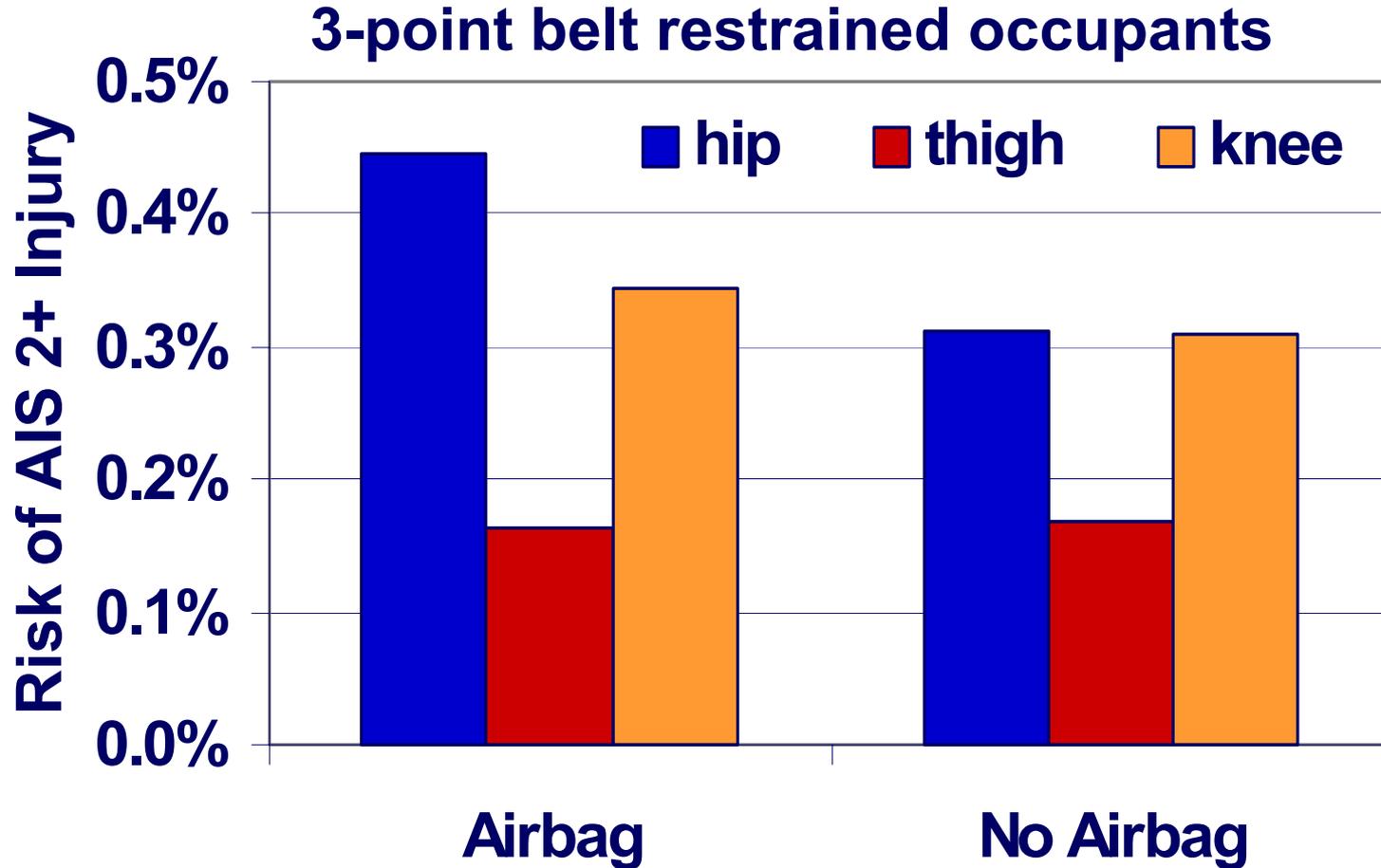
Risk of AIS 2+ Injury in Different Restraint Environments (NASS/CDS 1993-2001)



Annual LLI per 100 Front Seat Occupants in different Restraint Environments (NASS/CDS 1993-2001)

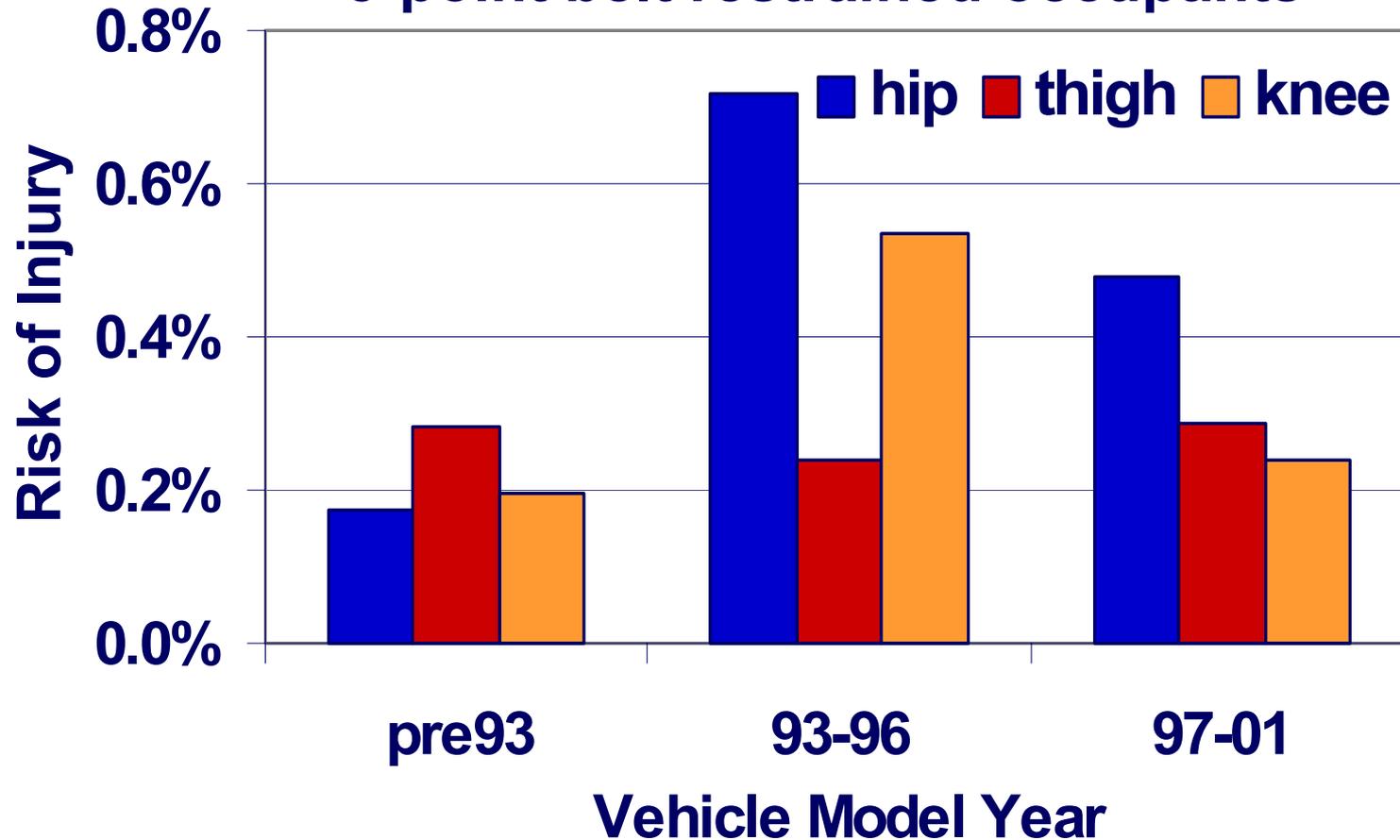


Risk of KTH injuries of restrained occupants by air bag presence (NASS/CDS 1993-2001)



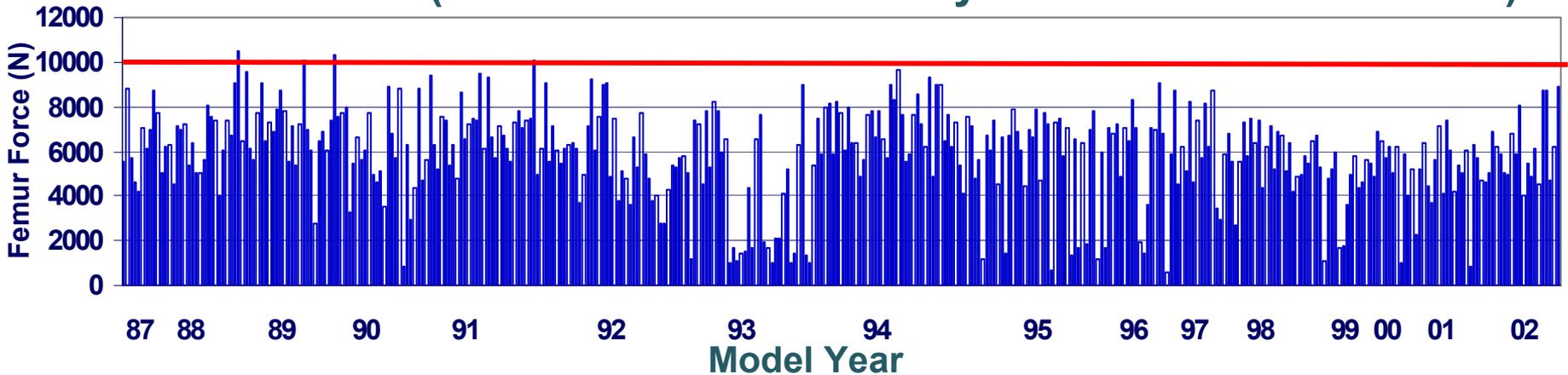
Risk of KTH Injuries in air bag equipped vehicles by vehicle model year (NASS/CDS 1993-2001)

3-point belt restrained occupants

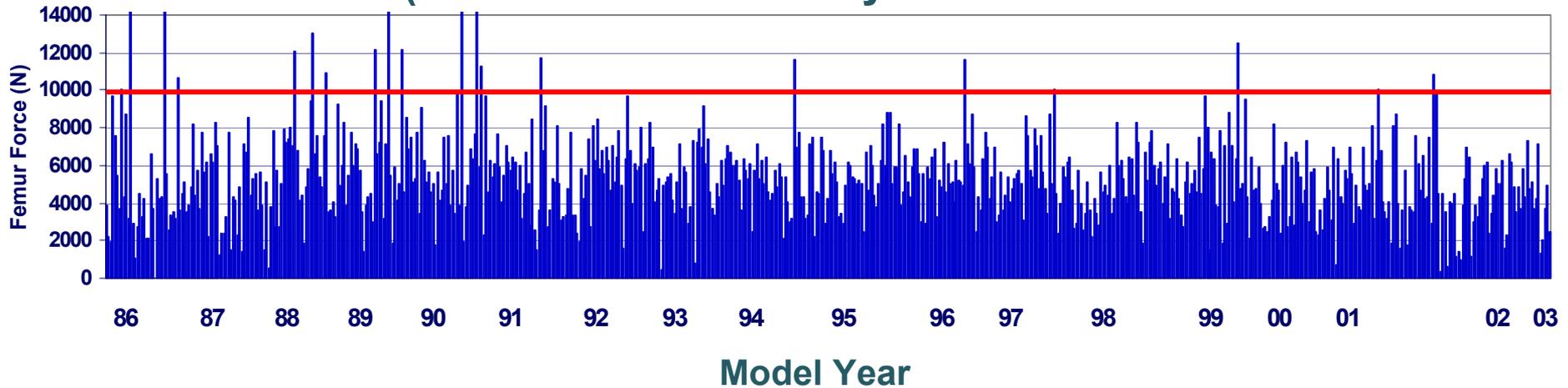


FMVSS 208 and NCAP Test Data

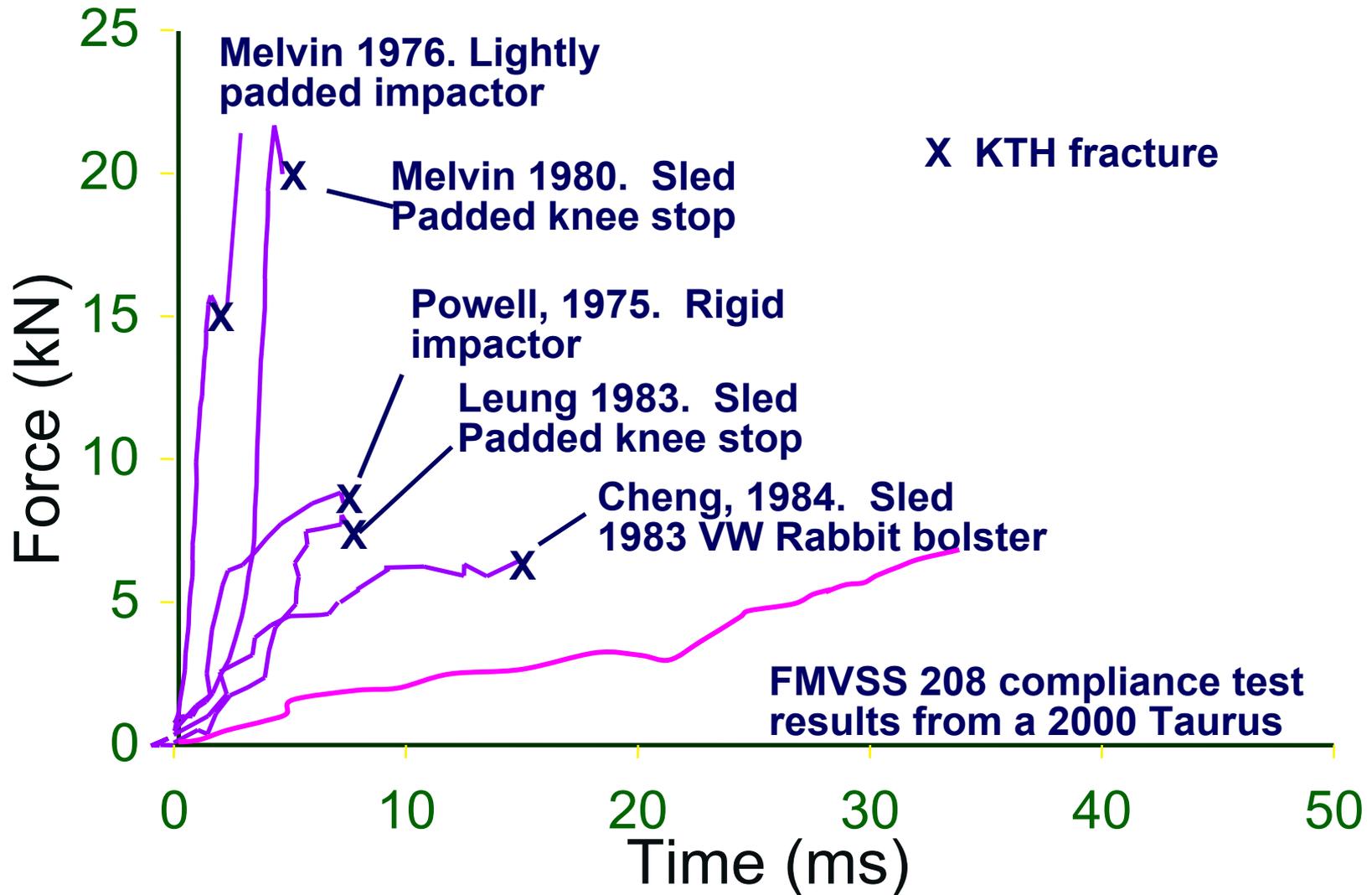
FMVSS 208 (unrestrained HII dummy in 48 km/h frontal crash)



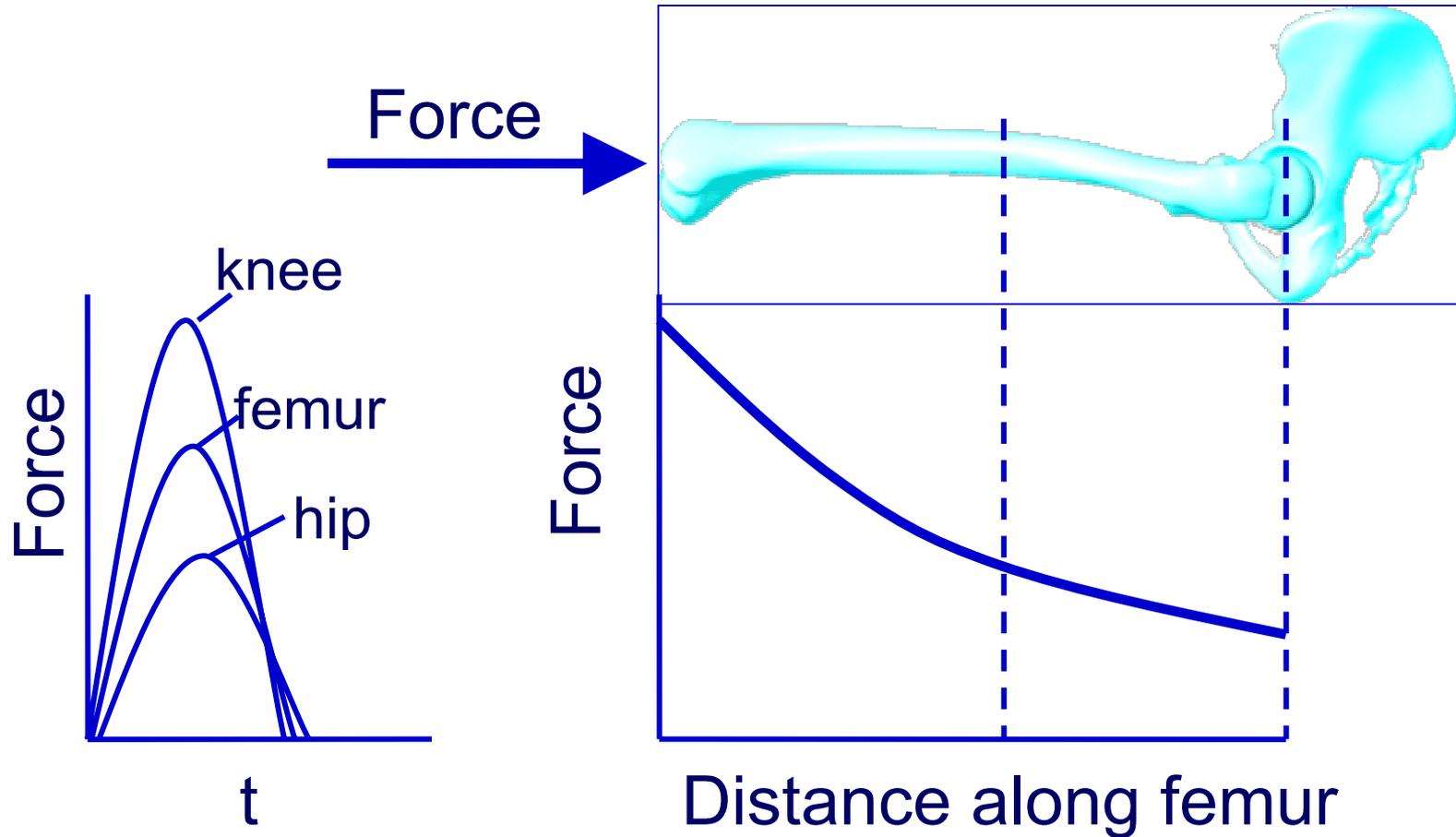
NCAP (restrained HII dummy in 56 km/h frontal crash)



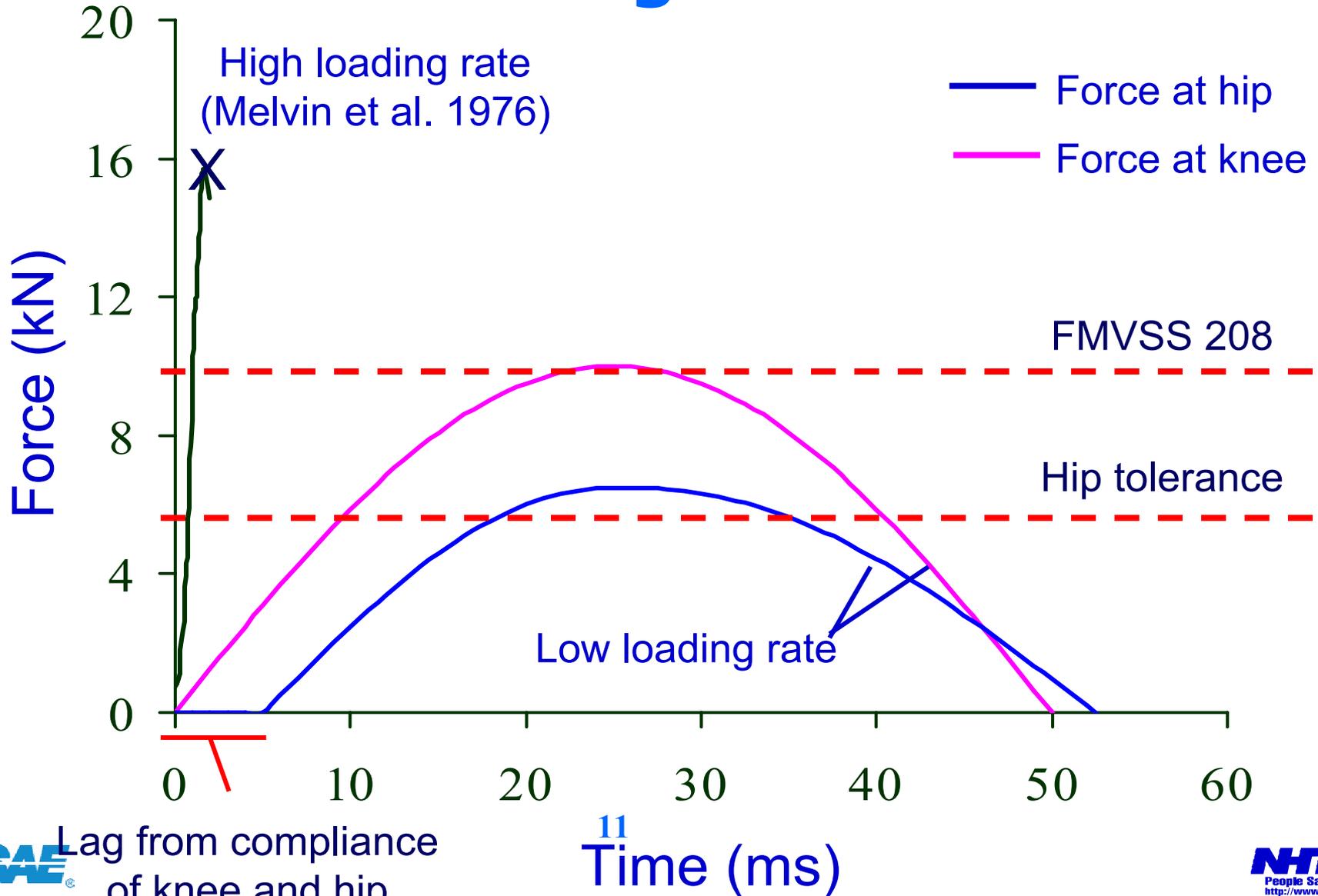
Loading Rates in Previous Studies



Inertial Effects on Loading of the KTH Complex



Effect of Joint Compliances on Short- and Long-Duration Loads

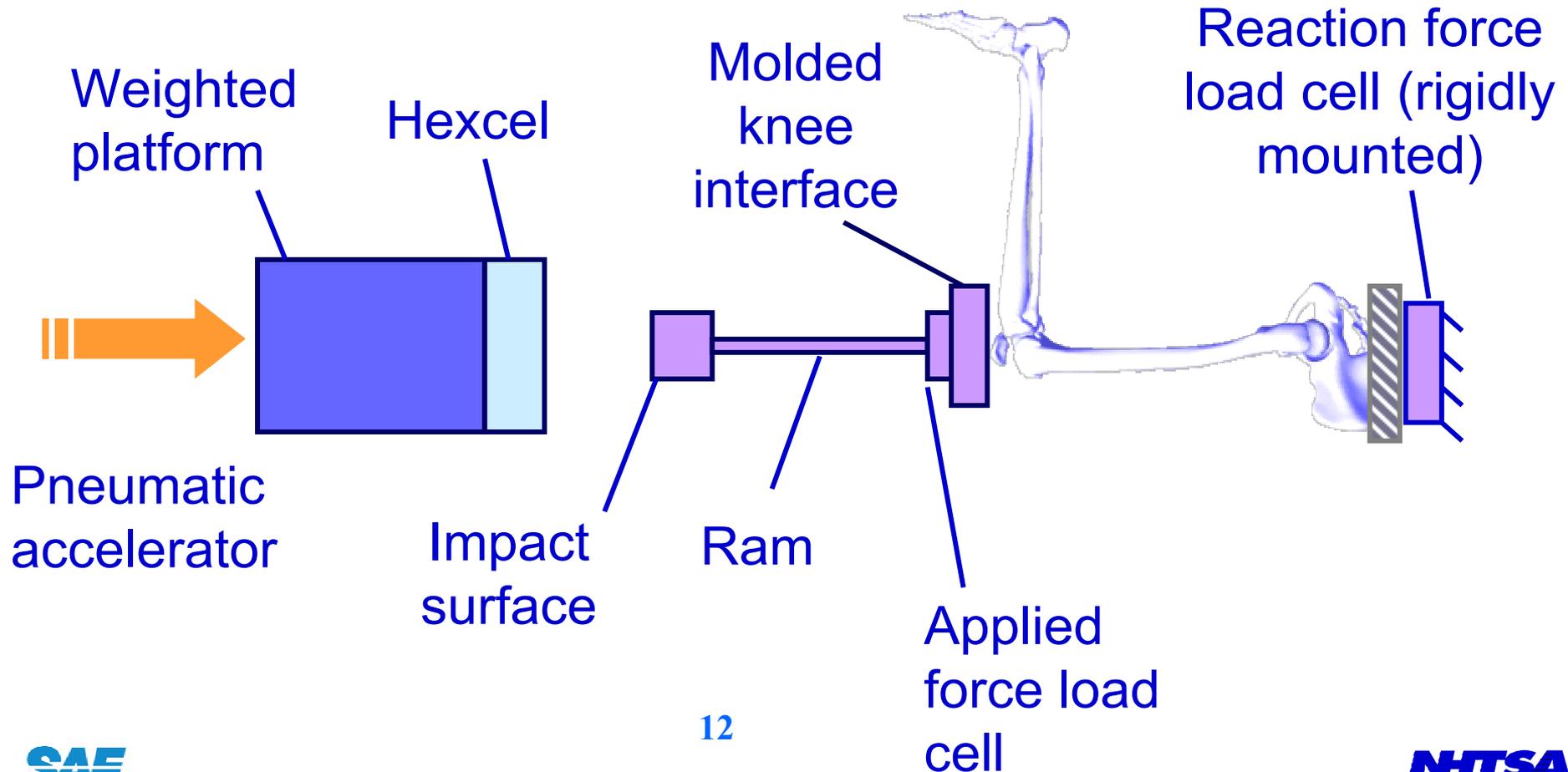


SAE Lag from compliance of knee and hip

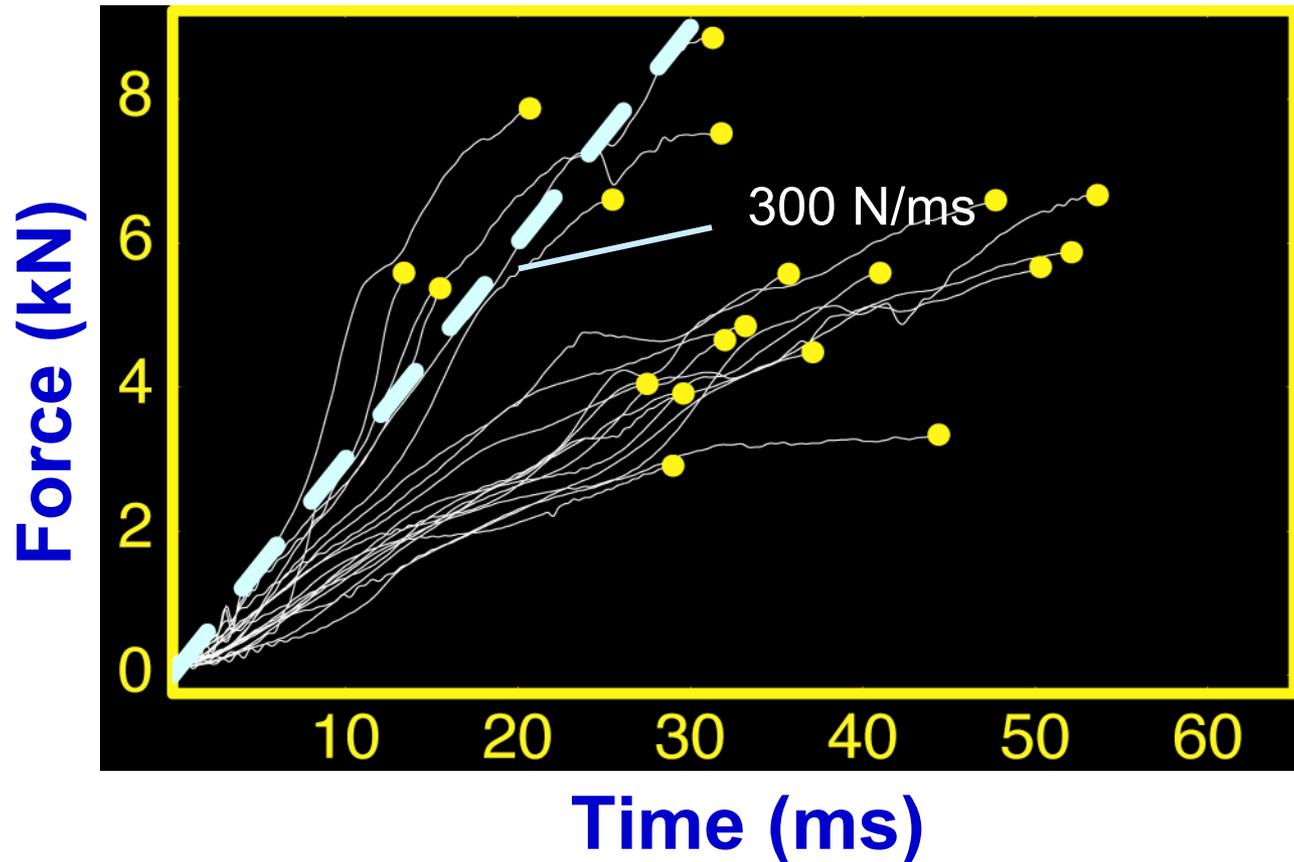
11 Time (ms)

UMTRI Hip Tolerance Testing

Schematic of test fixture



Rate of Loading in UMTRI Knee Impact Tests



Typical loading rates in FMVSS 208 tests are also less than 300 N/ms while the loading rates in previous research were 400-3000 N/ms.

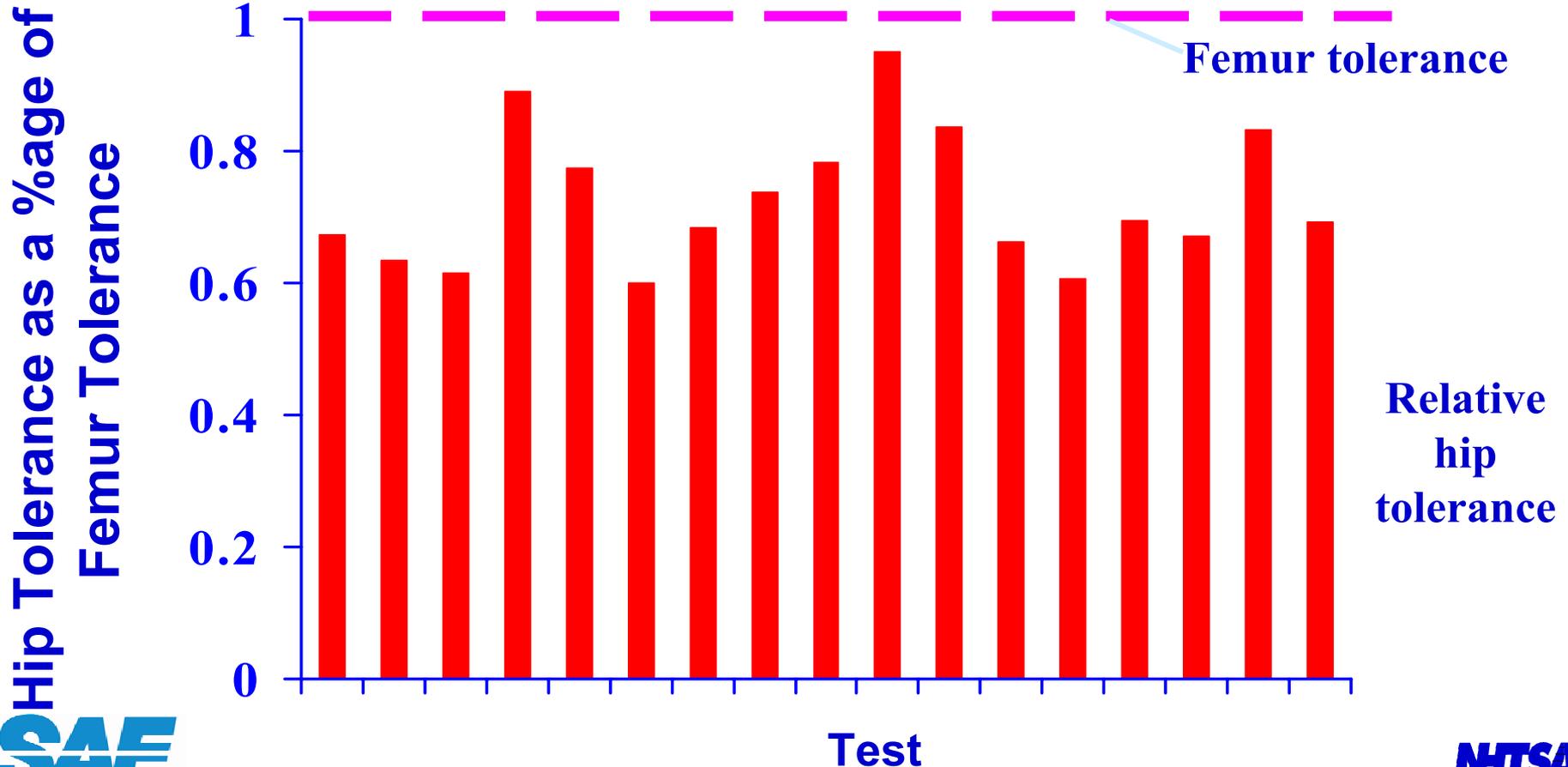
Femur Tolerance Testing

- Same apparatus as hip tolerance tests.
- Same specimens as those used in the hip tolerance tests with hip disarticulated and the head of femur inserted in an acetabular cup fixed to the support.



Femur Tolerance Testing

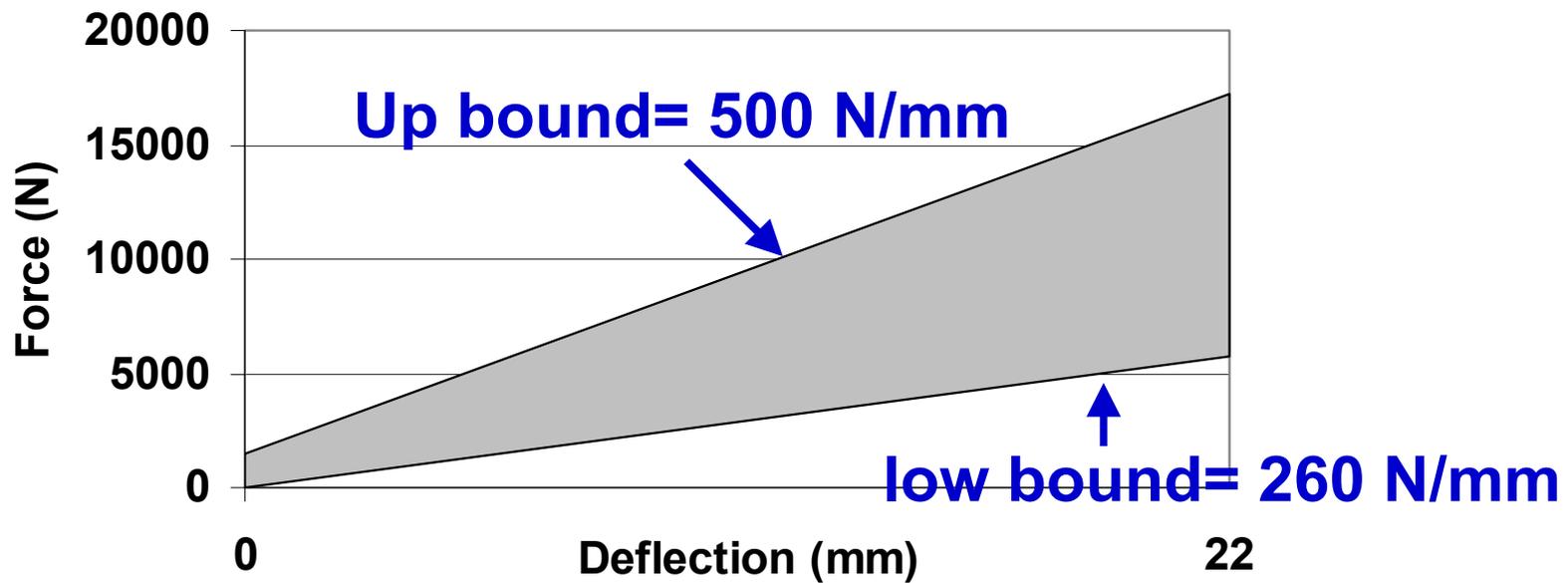
The femur is stronger than the acetabulum ($P < 0.01$)
Hip tolerance is $72 \pm 7\%$ of femur tolerance



Results of impact tests

- Neutral posture hip fracture tolerance is **5.7 ± 1.4 kN**
- Femur fracture tolerance is **7.6 ± 1.6 kN**
- Femoral neck is the weakest part of the femur.
- Using the displacement of the ram and the force applied at the knee,
 - The stiffness of knee-thigh-hip complex is **233 N/mm**
 - The stiffness of knee-femur complex is **370 ± 80 N/mm**

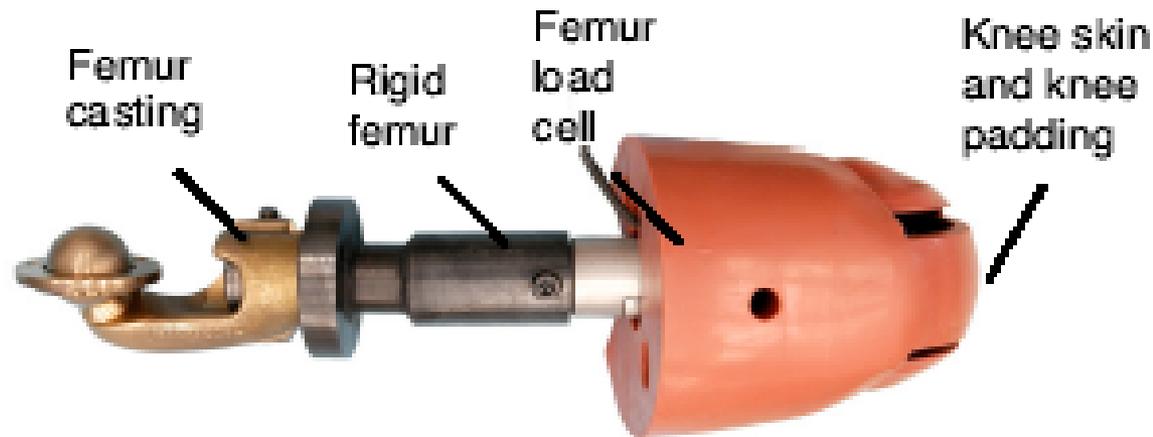
Stiffness of Human Cadaver Knee/Femur complex at loading rates seen in 30 mph frontal crashes (FMVSS208)



Most of the knee-femur axial compliance is due to femur bending rather than the compliance at the knee joint.

Hybrid III Knee-thigh-hip Complex

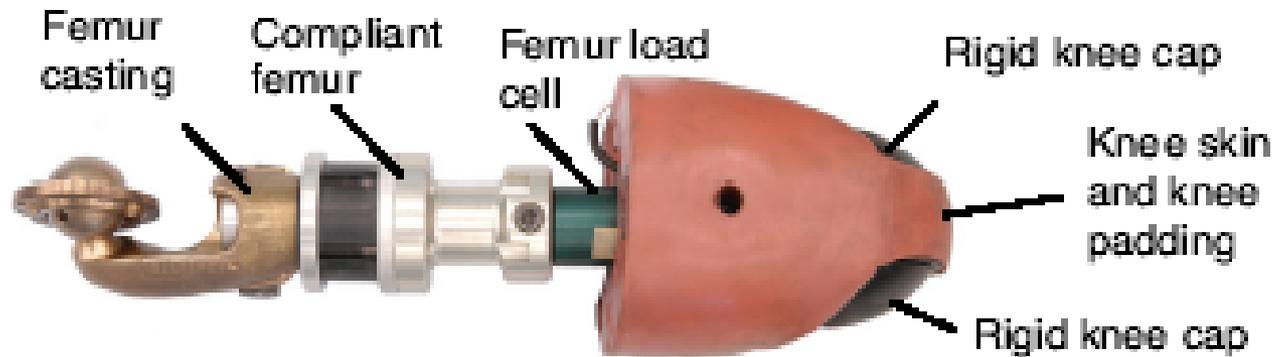
- Hybrid III knee-thigh stiffness based on fixed femur skeletal response of knee+distal femur sections by Horsch and Patrick (1976).



- Compliance of knee padding was selected such that HIII knee+distal femur response matches the Horsch-Patrick data
- Donnelly and Roberts (1987) found the Hybrid III to produce three times greater force than cadaveric subjects in whole-body knee impact tests.

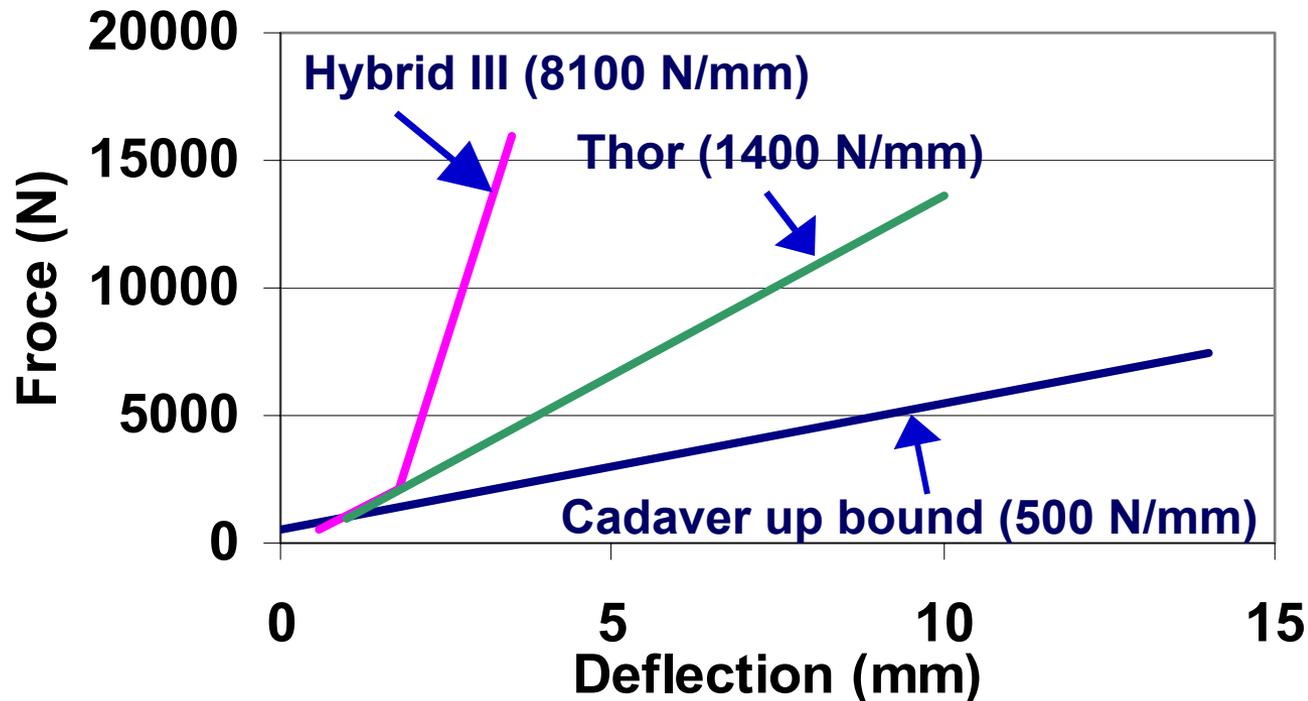
Thor Knee-thigh-hip Complex

- To better match Donnelly and Roberts data, Thor has a compliant element in the mid femur and redistributes some of the thigh mass to the flesh.



- The knee design is similar to the Hybrid III knee with similar impact response characteristics. It has rigid hemispherical knee caps intended to provide more human-like interaction with the knee bolster.

Knee-femur compliance of Hybrid III, Thor and cadaver in molded knee interface loading at rates similar to that seen in 30 mph frontal crashes



Initial stiffness (1800 N/mm) of Hybrid III knee-femur is due to compression of knee padding. After about 2 mm, the Hybrid III stiffness increases to 8100 N/mm, which reflects the rigidity of the femur and the limited compliance offered by knee padding.

Compliance of ATDs at typical loading rates seen in FMVSS 208 frontal crashes

Thor Knee/Femur Compliance =

3 X Cadaver Knee/Femur compliance

Hybrid III Knee/Femur Compliance =

16 X Cadaver Knee/Femur Compliance

The Thor has a less stiff force deflection response than the Hybrid III dummy due to the compliant element in the Thor femur

Biofidelity of ATDs

- Biofidelity of an ATD's knee-thigh complex depends on knee/femur stiffness, as well as inertial contributions of the knee/femur complex and other body regions.
- In order to address mass-coupling issues, knee impacts to whole body cadavers and ATDs (free back condition) will be conducted.
- Though the Thor knee-femur stiffness is 3 times greater than that of human cadavers, its response under dynamic knee loading, such as in frontal crashes, may be similar to that of human cadavers.

New Knee Bolster Designs



With the advent of new knee bolster designs, such as inflatable bolsters, the biofidelity of the knee-thigh-hip complex of the ATD and appropriate injury criteria will become crucial to ensure adequate protection for the KTH complex in frontal crashes.